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CHEMISTRY
HIGHER LEVEL
PAPER 2

Candidate session number

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Monday 9 May 2011 (afternoon)

2 hours 15 minutes

Examination code

2	2	1	1	–	6	1	1	4

INSTRUCTIONS TO CANDIDATES

- Write your session number in the boxes above.
- Do not open this examination paper until instructed to do so.
- Section A: answer all questions.
- Section B: answer two questions.
- Write your answers in the boxes provided.

0132

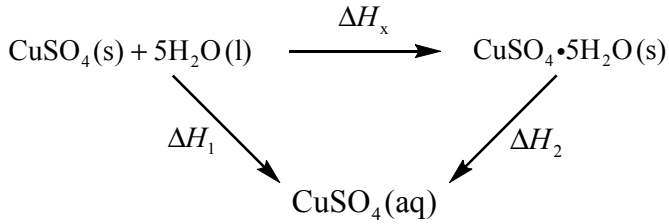
SECTION A

*Answer **all** questions. Write your answers in the boxes provided.*

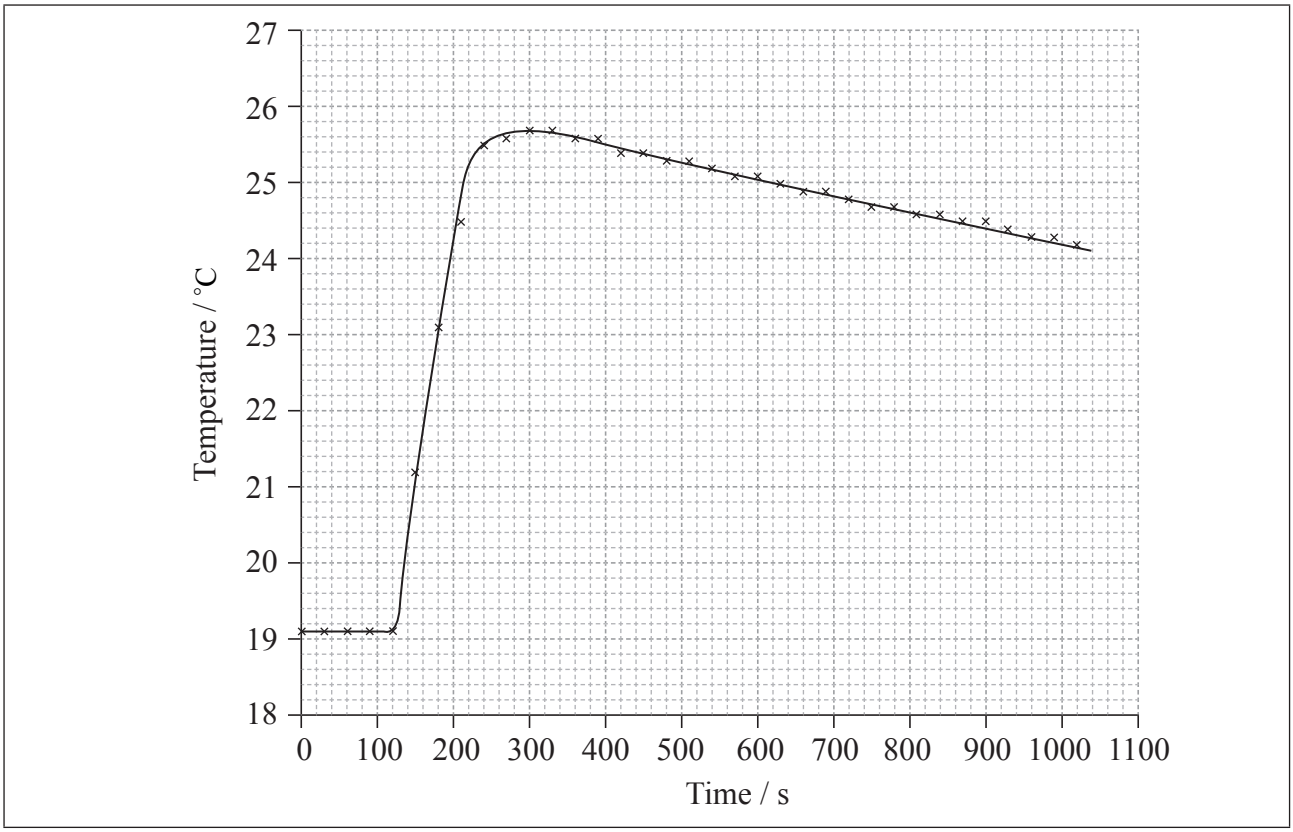
1. If white anhydrous copper(II) sulfate powder is left in the atmosphere it slowly absorbs water vapour giving the blue pentahydrated solid.

$$\underset{\text{(anhydrous)}}{CuSO_4(s)} + 5H_2O(l) \rightarrow \underset{\text{(pentahydrated)}}{CuSO_4 \bullet 5H_2O(s)}$$

It is difficult to measure the enthalpy change for this reaction directly. However, it is possible to measure the heat changes directly when both anhydrous and pentahydrated copper(II) sulfate are separately dissolved in water, and then use an energy cycle to determine the required enthalpy change value, ΔH_x, indirectly.



(a) To determine ΔH_1 a student placed 50.0 g of water in a cup made of expanded polystyrene and used a data logger to measure the temperature. After two minutes she dissolved 3.99 g of anhydrous copper(II) sulfate in the water and continued to record the temperature while continuously stirring. She obtained the following results.



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(Question 1 continued)

(i) Calculate the amount, in mol, of anhydrous copper(II) sulfate dissolved in the 50.0 g of water. *[1]*

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(ii) Determine what the temperature rise would have been, in °C, if no heat had been lost to the surroundings. *[2]*

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(iii) Calculate the heat change, in kJ, when 3.99 g of anhydrous copper(II) sulfate is dissolved in the water. *[2]*

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(iv) Determine the value of ΔH_1 in kJ mol^{-1}. *[1]*

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(Question 1 continued)

(b) To determine ΔH_2, 6.24 g of pentahydrated copper(II) sulfate was dissolved in 47.75 g of water. It was observed that the temperature of the solution decreased by 1.10 °C.

(i) Calculate the amount, in mol, of water in 6.24 g of pentahydrated copper(II) sulfate. *[2]*

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(ii) Determine the value of ΔH_2 in kJ mol^{-1}. *[2]*

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(iii) Using the values obtained for ΔH_1 in (a) (iv) and ΔH_2 in (b) (ii), determine the value for ΔH_x in kJ mol^{-1}. *[1]*

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(This question continues on the following page)

(Question 1 continued)

(c) The magnitude (the value without the + or – sign) found in a data book for ΔH_x is 78.0 kJ mol^{-1}.

(i) Calculate the percentage error obtained in this experiment. (If you did not obtain an answer for the experimental value of ΔH_x then use the value 70.0 kJ mol^{-1}, but this is **not** the true value.) *[1]*

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(ii) The student recorded in her qualitative data that the anhydrous copper(II) sulfate she used was pale blue rather than completely white. Suggest a reason why it might have had this pale blue colour and deduce how this would have affected the value she obtained for ΔH_x. *[2]*

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2. The element antimony, Sb, is usually found in nature as its sulfide ore, stibnite, Sb_2S_3. This ore was used two thousand years ago by ancient Egyptian women as a cosmetic to darken their eyes and eyelashes.

(a) (i) Calculate the percentage by mass of antimony in a sample of pure stibnite. State your answer to **four** significant figures. *[2]*

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(ii) Deduce the oxidation number of antimony in stibnite. *[1]*

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(iii) Deduce **one** other common oxidation number exhibited by antimony in some of its compounds. *[1]*

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(This question continues on the following page)

(Question 2 continued)

(b) One method of extracting antimony from its sulfide ore is to roast the stibnite in air. This forms antimony oxide and sulfur dioxide. The antimony oxide is then reduced by carbon to form the free element.

(i) Deduce the chemical equations for these **two** reactions. *[2]*

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(ii) Identify **two** different environmental concerns associated with this method of extraction. *[2]*

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(This question continues on the following page)

(Question 2 continued)

(c) Antimony contains two stable isotopes, ^{121}Sb and ^{123}Sb. The relative atomic mass of antimony is given in Table 5 of the Data Booklet.

(i) Calculate the percentage of each isotope in pure antimony. State your answers to **three** significant figures. *[2]*

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(ii) The percentage of each isotope can be checked experimentally using a mass spectrometer. A vaporized sample of pure antimony is ionized and then accelerated in a mass spectrometer. Outline how the use of a magnetic field and a detector in the mass spectrometer enables the percentages of the two isotopes to be determined. *[3]*

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(iii) State the number of neutrons present in an atom of ^{121}Sb. *[1]*

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3. (a) The electron configuration of chromium can be expressed as $[Ar]4s^x3d^y$.

(i) Explain what the square brackets around argon, [Ar], represent. *[1]*

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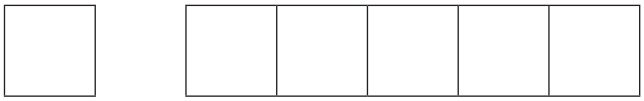
(ii) State the values of *x* and *y*. *[1]*

x: . . . . . .

y: . . . . . .

(iii) Annotate the diagram below showing the 4s and 3d orbitals for a chromium atom using an arrow, ↿ and ⇂, to represent a spinning electron. *[1]*



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(Question 3 continued)

(b) Hydrogen and nitrogen(II) oxide react according to the following equation.

$$2H_2(g) + 2NO(g) \rightleftharpoons N_2(g) + 2H_2O(g)$$

At time = t seconds, the rate of the reaction is

$$\text{rate} = k[H_2(g)][NO(g)]^2$$

(i) Explain precisely what the square brackets around nitrogen(II) oxide, $[NO(g)]$, represent in this context. *[1]*

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(ii) Deduce the units for the rate constant k. *[1]*

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(Question 3 continued)

(c) When concentrated hydrochloric acid is added to a solution containing hydrated copper(II) ions, the colour of the solution changes from light blue to green. The equation for the reaction is:

$$[Cu(H_2O)_6]^{2+}(aq) + 4Cl^-(aq) \rightarrow [CuCl_4]^{2-}(aq) + 6H_2O(l)$$

(i) Explain what the square brackets around the copper containing species represent. *[1]*

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(ii) Explain why the $[Cu(H_2O)_6]^{2+}$ ion is coloured and why the $[CuCl_4]^{2-}$ ion has a different colour. *[2]*

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(d) Some words used in chemistry can have a specific meaning which is different to their meaning in everyday English.

State what the term *spontaneous* means when used in a chemistry context. *[1]*

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4. Methoxymethane, CH_3OCH_3, and ethanol, C_2H_5OH, have the same relative molecular mass. Explain why methoxymethane has a much lower boiling point than ethanol. *[3]*

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SECTION B

*Answer **two** questions. Write your answers in the boxes provided.*

5. (a) Ammonia, NH_3, is a weak base. It has a pK_b value of 4.75.

(i) Draw the Lewis structure of ammonia and state the shape of the molecule and its bond angles. *[3]*

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(ii) The conjugate acid of ammonia is the ammonium ion, NH_4^+. Draw the Lewis structure of the ammonium ion and deduce its shape and bond angles. *[3]*

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(iii) Another weak base is nitrogen trifluoride, NF_3. Explain how NF_3 is able to function as a Lewis base. *[1]*

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(This question continues on the following page)

(Question 5 continued)

(iv) Calculate the pH of a $1.00 \times 10^{-2}\,\text{mol dm}^{-3}$ aqueous solution of ammonia at 298 K. *[4]*

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(v) 25.0 cm^3 of $1.00 \times 10^{-2}\,\text{mol dm}^{-3}$ hydrochloric acid solution is added to 50.0 cm^3 of $1.00 \times 10^{-2}\,\text{mol dm}^{-3}$ aqueous ammonia solution. Calculate the concentrations of both ammonia and ammonium ions in the resulting solution and hence determine the pH of the solution. *[5]*

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(Question 5 continued)

(vi) State what is meant by a buffer solution and explain how the solution in (v), which contains ammonium chloride dissolved in aqueous ammonia, can function as a buffer solution. *[3]*

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(b) Salts may form neutral, acidic or alkaline solutions when dissolved in water.

(i) Explain why a solution of sodium chloride is neutral but sodium carbonate forms an alkaline solution when it dissolves in water. *[2]*

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(ii) Explain why iron(III) chloride, $[Fe(H_2O)_6]Cl_3$, forms an acidic solution in water. *[2]*

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(This question continues on the following page)

(Question 5 continued)

(iii) State the equations for the reactions of sodium oxide, Na_2O, and phosphorus(V) oxide, P_4O_{10}, with water. *[2]*

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6. (a) An example of a homogeneous reversible reaction is the reaction between hydrogen and iodine.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

(i) Outline the characteristics of a homogeneous chemical system that is in a state of equilibrium. *[2]*

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(ii) Deduce the expression for the equilibrium constant, K_c. *[1]*

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(iii) Predict what would happen to the position of equilibrium if the pressure is increased from 1 atm to 2 atm. *[1]*

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(iv) The value of K_c at 500 K is 160 and the value of K_c at 700 K is 54. Deduce what this information tells us about the enthalpy change of the forward reaction. *[1]*

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(Question 6 continued)

(v) At a temperature just above 700 K it is found that when 1.60 mol of hydrogen and 1.00 mol of iodine are allowed to reach equilibrium in a 4.00 dm^3 flask, the amount of hydrogen iodide formed in the equilibrium mixture is 1.80 mol. Determine the value of the equilibrium constant at this temperature. *[4]*

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(vi) The reaction can be catalysed by adding platinum metal. State and explain what effect the addition of platinum would have on the value of the equilibrium constant. *[2]*

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(Question 6 continued)

(b) Propene can be hydrogenated in the presence of a nickel catalyst to form propane. Use the data below to answer the questions that follow.

Compound	Formula	$\Delta H^{\ominus}_f$ / kJ mol^{-1}	$S^{\ominus}$ / J K^{-1} mol^{-1}
hydrogen	$H_2(g)$	0	+131
propane	$C_3H_8(g)$	–104	+270
propene	$C_3H_6(g)$	+20.4	+267

(i) Outline why the value for the standard enthalpy change of formation of hydrogen is zero. *[1]*

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(ii) Calculate the standard enthalpy change for the hydrogenation of propene. *[2]*

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(iii) Calculate the standard entropy change for the hydrogenation of propene. *[2]*

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(This question continues on the following page)

(Question 6 continued)

(iv) Determine the value of $\Delta G^{\ominus}$ for the hydrogenation of propene at 298 K. *[2]*

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(v) At 298 K the hydrogenation of propene is a spontaneous process. Determine the temperature above which propane will spontaneously decompose into propene and hydrogen. *[2]*

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(c) (i) Describe a chemical test that could be used to distinguish between propane and propene. In **each** case state the result of the test. *[2]*

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(This question continues on the following page)

(Question 6 continued)

(ii) Under certain conditions propene can polymerize to form poly(propene). State the type of polymerization taking place and draw a section of the polymer to represent the repeating unit. *[2]*

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(iii) Other than polymerization, state **one** reaction of alkenes which is of economic importance. *[1]*

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7. (a) The standard electrode potential for a half-cell made from iron metal in a solution of iron(II) ions, $Fe^{2+}(aq)$, has the value –0.45 V.

(i) Define *standard electrode potential*. *[2]*

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(ii) Explain the significance of the minus sign in –0.45 V. *[1]*

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(Question 7 continued)

(b) Consider the following table of standard electrode potentials.

	$E^{\ominus}$ / V
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	−0.45
$Sn^{2+}(aq) + 2e^- \rightleftharpoons Sn(s)$	−0.14
$H^+(aq) + e^- \rightleftharpoons \frac{1}{2}H_2(g)$	0.00
$Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq)$	+0.15
$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$	+0.77
$Ag^+(aq) + e^- \rightleftharpoons Ag(s)$	+0.80
$\frac{1}{2}Br_2(l) + e^- \rightleftharpoons Br^-(aq)$	+1.07

From the list above:

(i) State the species which is the strongest oxidizing agent. *[1]*

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(ii) Deduce which species can reduce $Sn^{4+}(aq)$ to $Sn^{2+}(aq)$ but will not reduce $Sn^{2+}(aq)$ to $Sn(s)$ under standard conditions. *[1]*

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(iii) Deduce which species can reduce $Sn^{2+}(aq)$ to $Sn(s)$ under standard conditions. *[1]*

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(Question 7 continued)

(c) (i) Draw a labelled diagram of a voltaic cell made from an $Fe(s) / Fe^{2+}(aq)$ half-cell connected to an $Ag(s) / Ag^{+}(aq)$ half-cell operating under standard conditions. In your diagram identify the positive electrode (cathode), the negative electrode (anode) and the direction of electron flow in the external circuit. *[5]*

(ii) Deduce the equation for the chemical reaction occurring when the cell in part (c) (i) is operating under standard conditions and calculate the voltage produced by the cell. *[2]*

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(Question 7 continued)

(d) An acidified solution of potassium dichromate is often used as an oxidizing agent in organic chemistry. During the oxidation reaction of ethanol to ethanal the dichromate ion is reduced to chromium(III) ions according to the following **unbalanced** half-equation.

$$Cr_2O_7^{2-}(aq) + H^+(aq) + e^- \rightarrow Cr^{3+}(aq) + H_2O(l)$$

(i) Describe the colour change that will be observed in the reaction. *[1]*

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(ii) Deduce the oxidation number of chromium in $Cr_2O_7^{2-}$. *[1]*

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(iii) State the balanced half-equation for the reduction of dichromate ions to chromium(III) ions. *[1]*

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(This question continues on the following page)

(Question 7 continued)

(iv) Deduce the half-equation for the oxidation of ethanol to ethanal and hence the overall redox equation for the oxidation of ethanol to ethanal by acidified dichromate ions. *[3]*

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(v) Explain why it is necessary to carry out the reaction under acidic conditions. *[1]*

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(vi) Identify the organic product formed if excess potassium dichromate is used and the reaction is carried out under reflux. *[1]*

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(This question continues on the following page)

(Question 7 continued)

(e) Sodium metal can be obtained by the electrolysis of molten sodium chloride.

(i) Explain why it is very difficult to obtain sodium from sodium chloride by any other method. *[2]*

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(ii) Explain why an aqueous solution of sodium chloride cannot be used to obtain sodium metal by electrolysis. *[2]*

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8. There are several structural isomers with the molecular formula $C_5H_{11}Br$.

(a) Deduce the name of **one** of the isomers which can exist as enantiomers and draw three-dimensional representations of its **two** enantiomers. *[3]*

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(b) All the isomers react when warmed with a dilute aqueous solution of sodium hydroxide according to the equation below.

$$C_5H_{11}Br + NaOH \rightarrow C_5H_{11}OH + NaBr$$

(i) The reaction with 1-bromopentane proceeds by an S_N2 mechanism. Describe this mechanism using structural formulas and curly arrows to represent the movement of electron pairs. *[3]*

(This question continues on the following page)

(Question 8 continued)

(ii) The reaction with 2-bromo-2-methylbutane proceeds by an S_N1 mechanism. Describe this mechanism using structural formulas and curly arrows to represent the movement of electron pairs. *[3]*

(iii) Explain why 1-bromopentane reacts by an S_N2 mechanism whereas 2-bromo-2-methylbutane reacts by an S_N1 mechanism. *[3]*

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(Question 8 continued)

(iv) Explain whether the boiling point of 1-bromopentane will be higher, lower or the same as that of 2-bromo-2-methylbutane. *[3]*

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(v) The product $C_5H_{11}OH$ formed from the reaction with 1-bromopentane is warmed with ethanoic acid in the presence of a few drops of concentrated sulfuric acid. State the name of the type of reaction taking place and the structural formula of the organic product. *[2]*

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(This question continues on the following page)

(Question 8 continued)

(c) If the conditions of the reaction in (b) are changed so that a hot solution of sodium hydroxide in ethanol is used then a different reaction occurs. The reaction with 2-bromo-2-methylbutane gives **two** different organic products. State the type of reaction taking place and suggest the identity (name or structure) of these **two** products. Explain whether or not they can exist as geometrical isomers. *[4]*

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(d) Dihalogenoalkanes can also react with warm dilute potassium hydroxide solution to form diols. These diols can react with dicarboxylic acids.

(i) Deduce the equation for the reaction of benzene-1,4-dicarboxylic acid with the diol formed from 1,5-dibromopentane. *[3]*

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(ii) Outline the economic importance of the reaction of diols with dicarboxylic acids. *[1]*

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Answers written on this page
will not be marked.